The Good, the Bad, and the Ugly: Stratospheric Ozone, Tropospheric Ozone, and Ozone Change

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Outline

- Ozone and UV radiation - basic facts
- The ozone balance between production and destruction
- Ozone levels around the globe
- Ozone trends
- Summary
- If you're bored: http://www.dack.com/web/bullshit.html

Ozone Basic Facts

O_3 = Ozone is composed of 3 oxygen atoms.
O_3 inhalation becomes a problem at concentrations greater than 80 parts per billion sustained during a continuous 8-hour period (EPA).
O_3 absorbs harmful solar ultraviolet radiation. A necessary condition for life.
O_3 is mainly found in the the stratosphere.
O_3 heats the stratosphere.
O_3 concentrations are small (peak concentrations are about 10 parts per million at an altitude of about 32 km (20 miles).

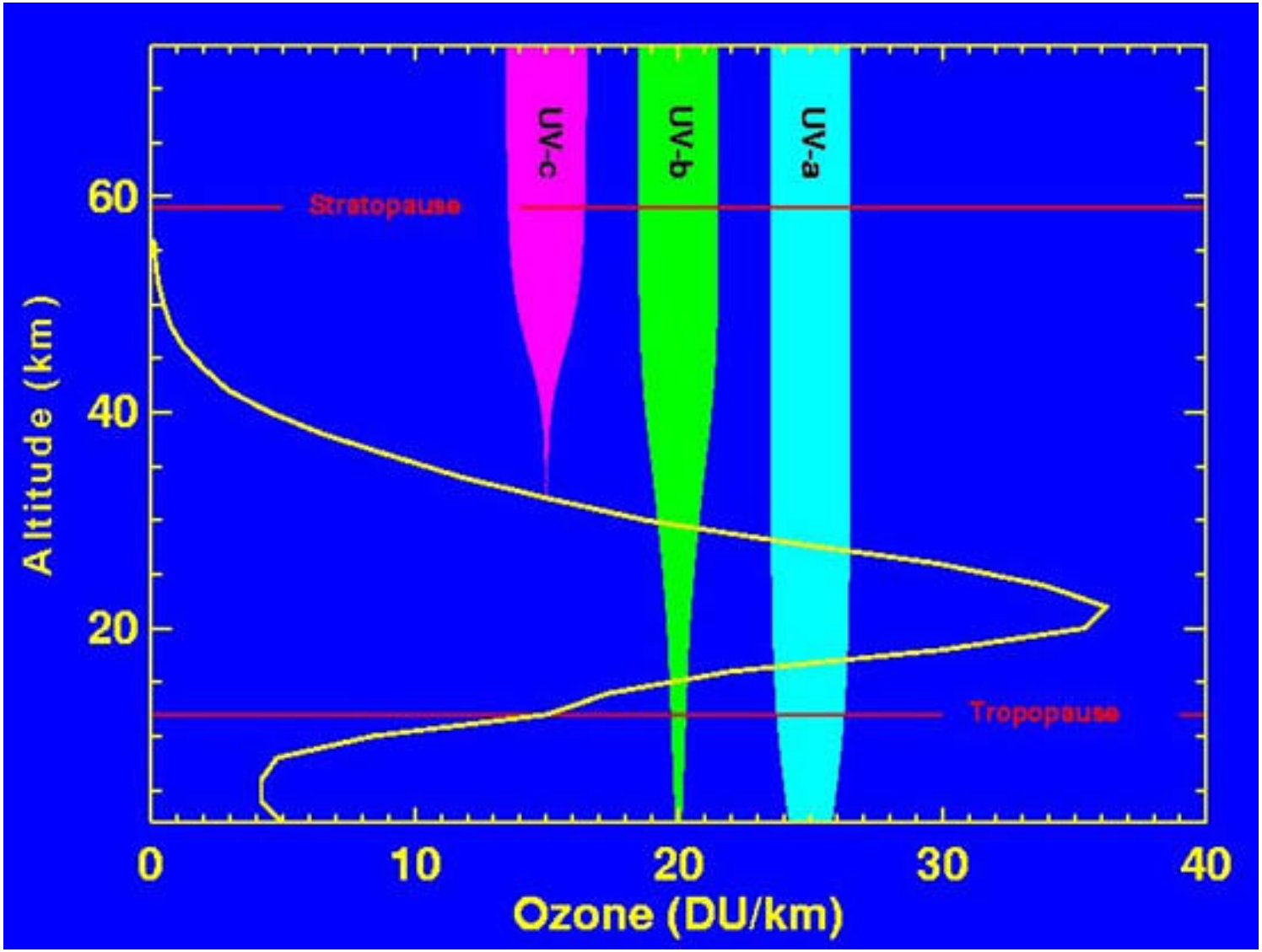
Mass: (Billion Metric Tons)

Sun	**1,9900,000,000,000,000,000**
Earth	**5,980,000,000,000**
Global atmosphere	**5,300,000**
Global ozone	**3**

UV radiation

- Solar radiation exists at a variety of wavelengths, most commonly visible radiation from 400 nm (nanometers or billionths of a meter) to about 700 nm.
- UV radiation extends from 1-400 nm (invisible to the human eye).
- http://sohowww.nascom.nasa.gov/data/realtime-images.html Extreme UV images from the Extreme ultraviolet Imaging Telescope (EIT)
- A UV photon is more energetic than a visible photon, and the UV photon can break the bonds of biological molecules such as proteins and DNA.

Ozone screens UV radiation

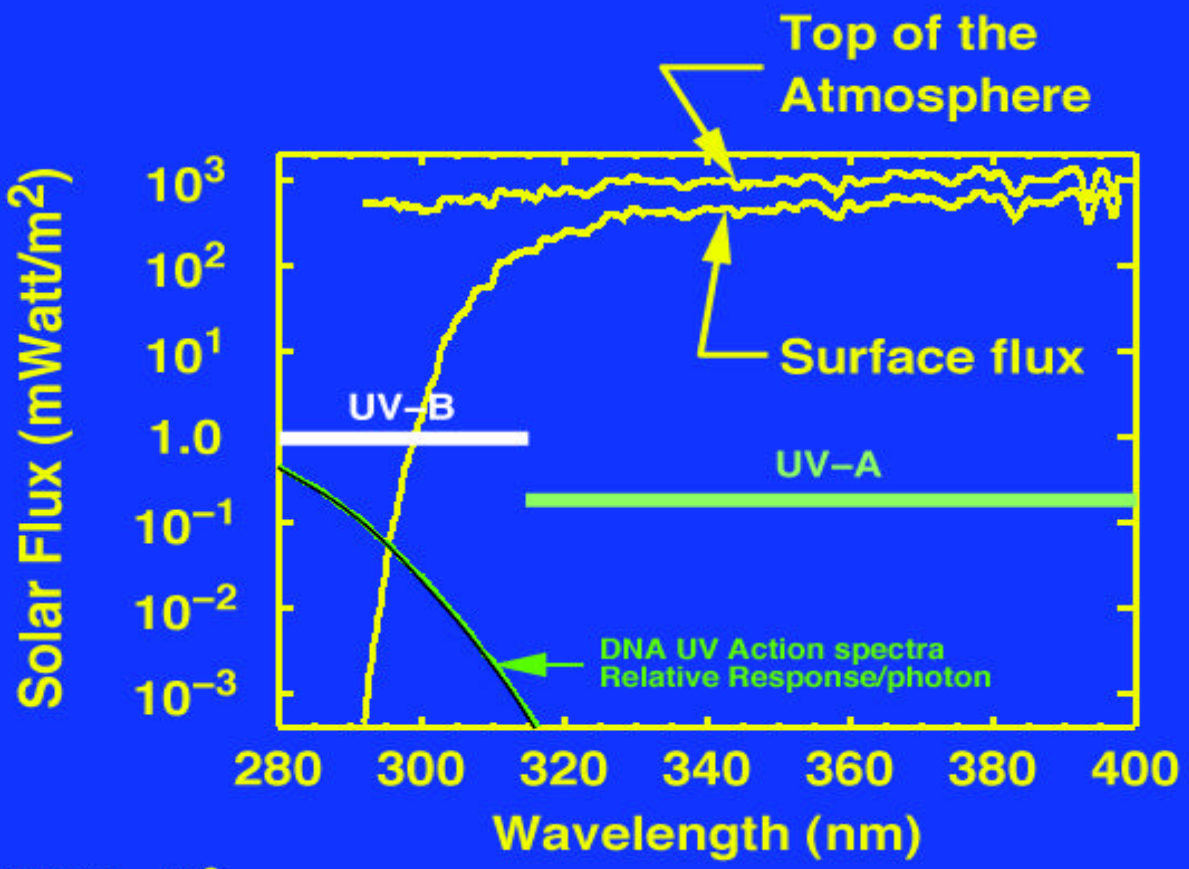


Ozone absorbs the sun's harmful ultraviolet radiation

UV-c = 200-280 nm, very strongly absorbed by oxygen & ozone
UV-b = 280-320 nm, strongly absorbed by ozone
UV-a = 320-400 nm, weakly absorbed by ozone

- Eye damage: cataracts, photokerititus (snowblinding), ocular cancers
- Skin cancers: basal, squamous, melanoma
- photoaging
- Damage to various land species: cancers, altered gene activity, altered species interactions
- Damage to aquatic species: altered growth & biological processes of phytoplankton (basis of food web), altered growth of sea grasses & macroalgae., altered zooplankton
- Increased pollution levels in urban environments
- Health: http://www.ciesin.org/TG/HH/ozhlthhm.html and http://www.aad.org/Marketplace/shopping/sunprotection.html

Absorption of UV radiation by ozone

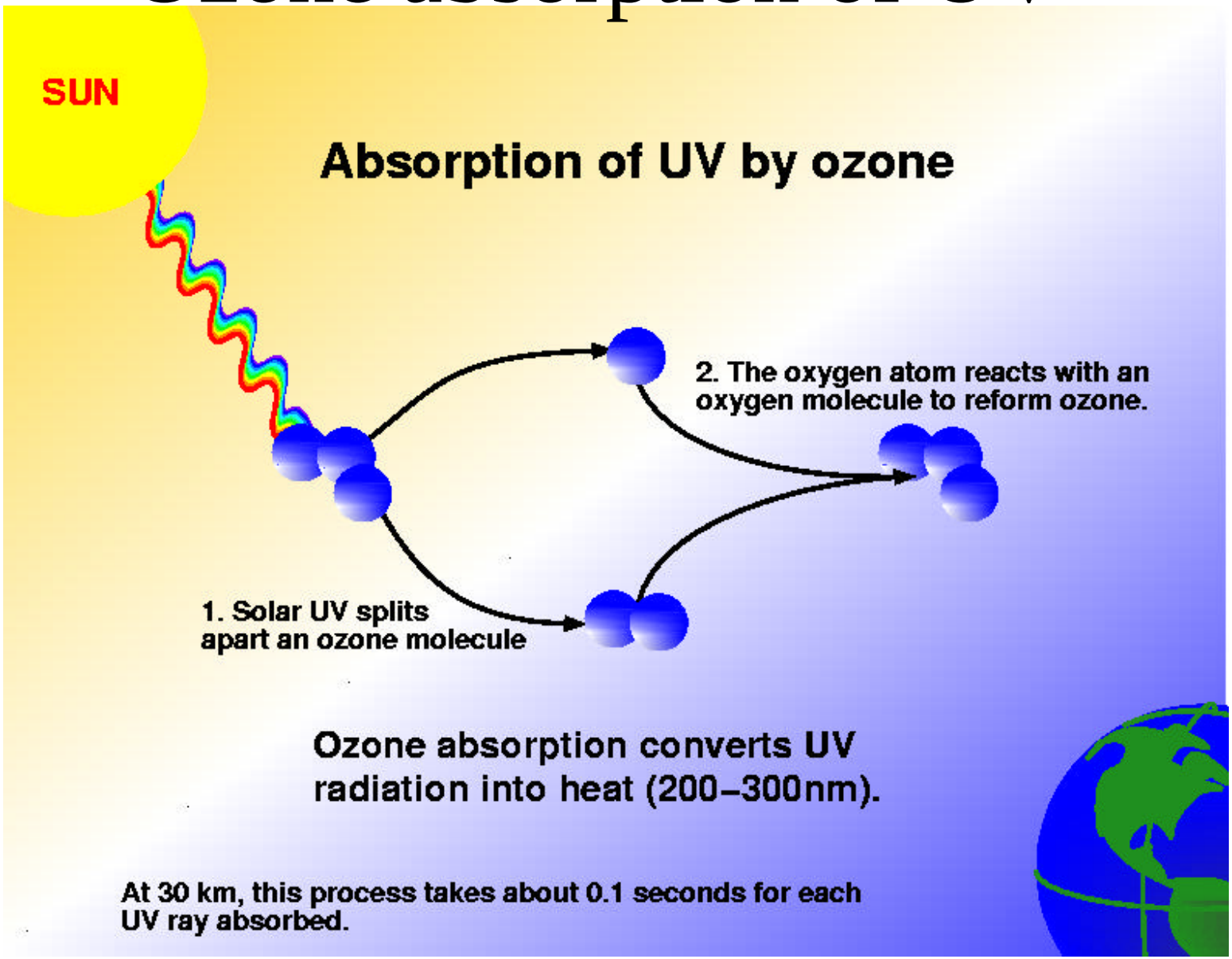


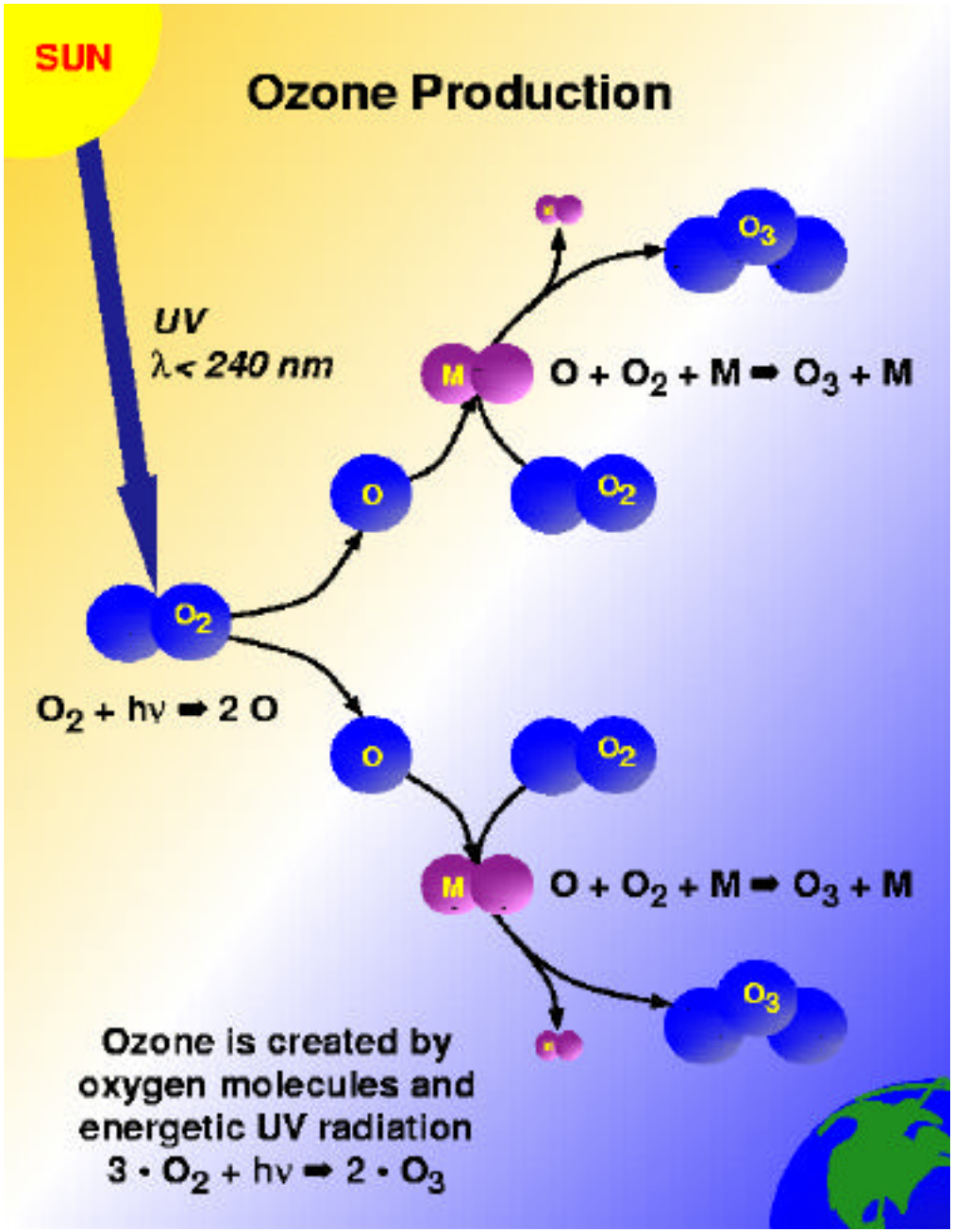
solar zenith = 45°
surface refl. = 0%
total ozone = 325 DU

The UV flux at the surface is controlled by clouds, ozone, the sun's elevation, and local pollution. Top of the atmosphere spectra from UARS SOLSTICE.

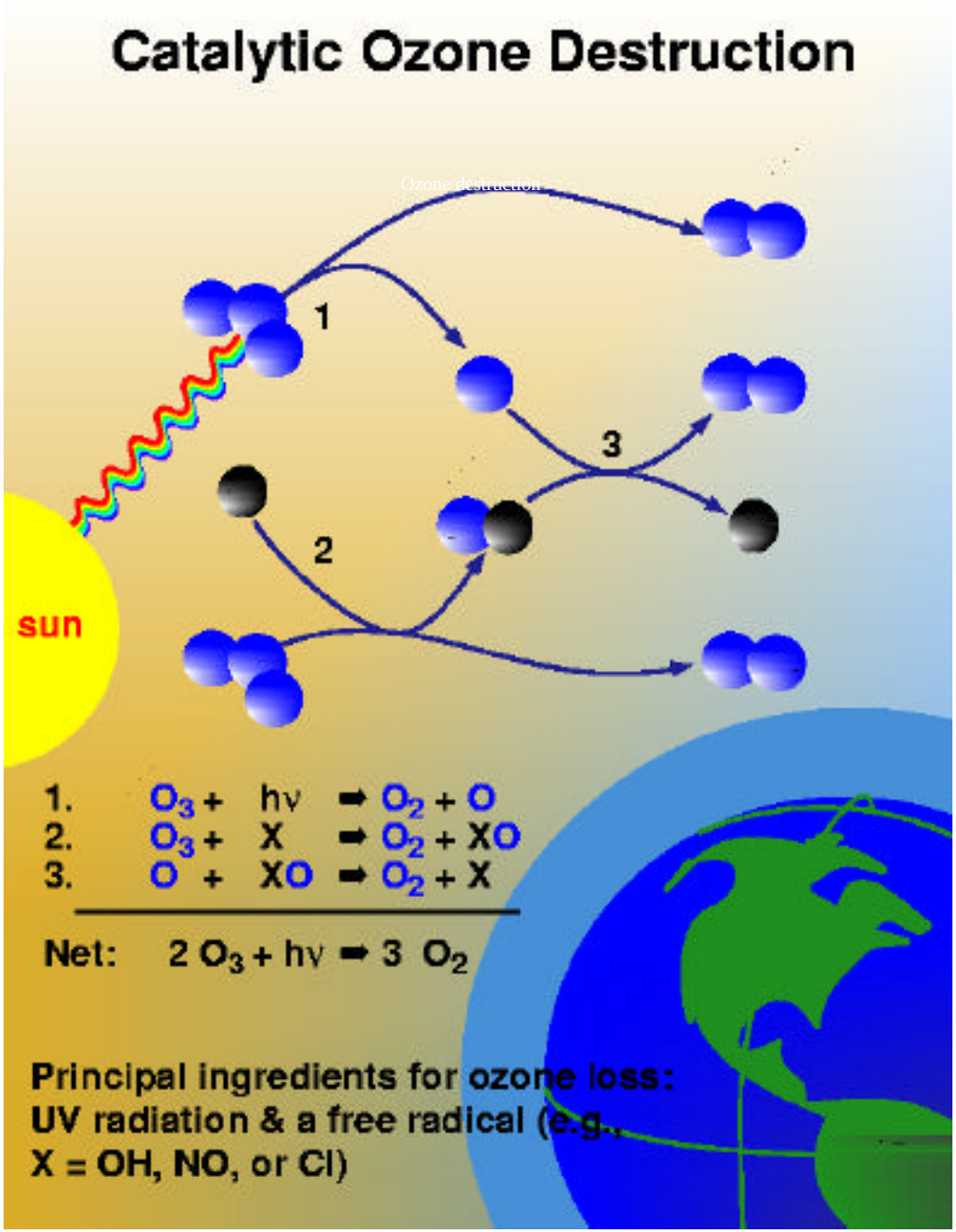
· UV–B Monitoring Workshop

Ozone absorption of UV



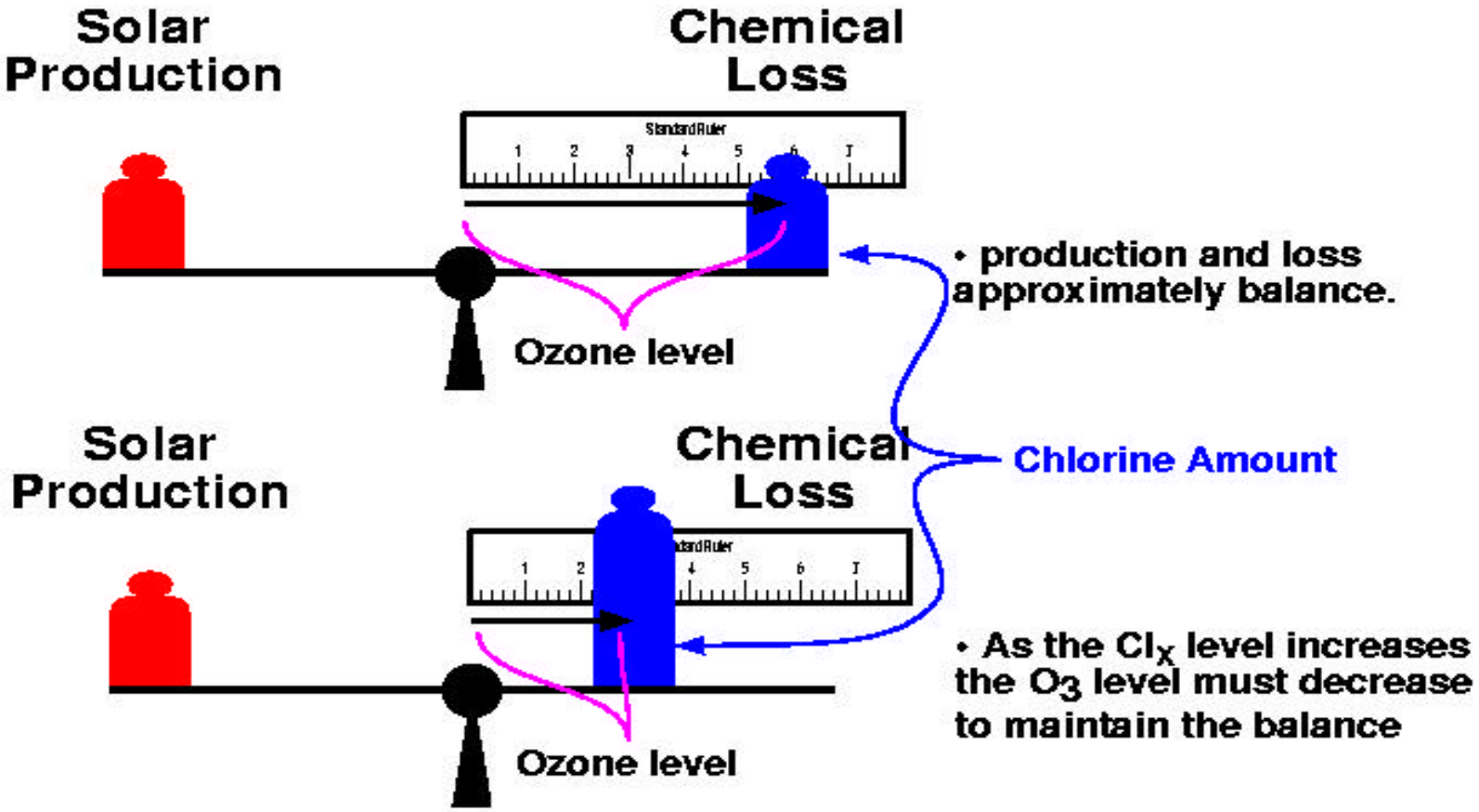

SUN
Ozone Production
UV
λ< 240 nm
O + O2 + M ➡ O3 + M
O2 + hν ➡ 2 O
O + O2 + M ➡ O3 + M
Ozone is created by
oxygen molecules and
energetic UV radiation
3 • O2 + hν ➡ 2 • O3

Ozone Production Movie


Catalytic Ozone Destruction
Ozone destruction
1
2
3
sun
1. $O_3 + h\nu \rightarrow O_2 + O$
2. $O_3 + X \rightarrow O_2 + XO$
3. $O + XO \rightarrow O_2 + X$
Net: $2\,O_3 + h\nu \rightarrow 3\,O_2$
Principal ingredients for ozone loss:
UV radiation & a free radical (e.g.,
X = OH, NO, or Cl)

Ozone Destruction Movie

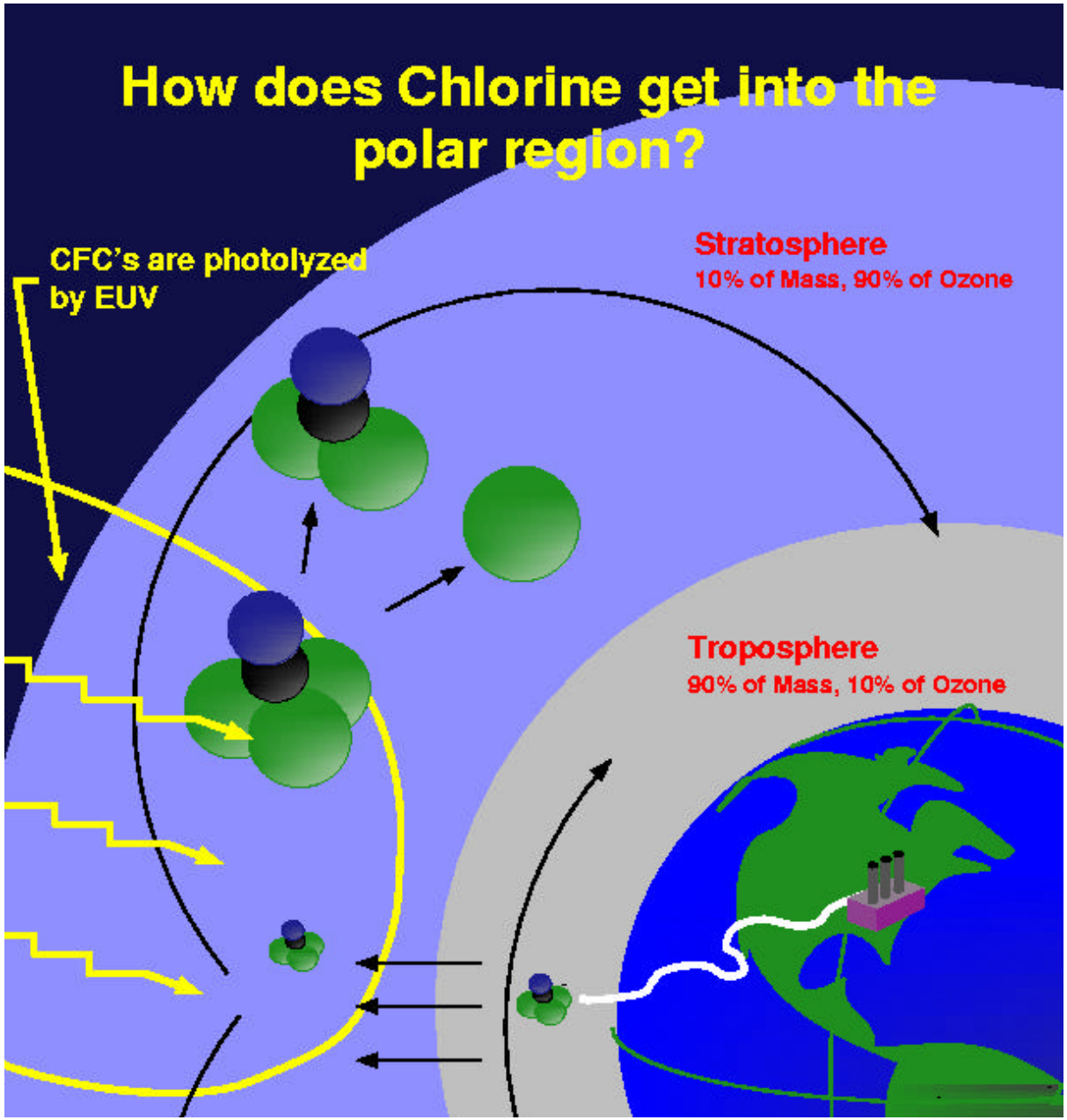
Photochemical balance



$$P = k\, O_3\, Cl_X$$

Source Gases for Stratospheric Ozone Loss

- NO_x - Nitrous Oxide (N_2O)
- HO_x - Methane (CH_4), Water (H_2O)
- **ClO_x** - Methyl Chloride (CH_3Cl), CFCs (e.g., F11: $CFCl_3$, F-12: CF_2Cl_2, F113: CF_3CCl_3, etc.)
- **BrO_x** - Methyl Bromide (CH_3Br), Halons (CF_2BR_2, CF_2ClBr)


How does Chlorine get into the polar region?
CFC's are photolyzed by EUV
Stratosphere
10% of Mass, 90% of Ozone
Troposphere
90% of Mass, 10% of Ozone

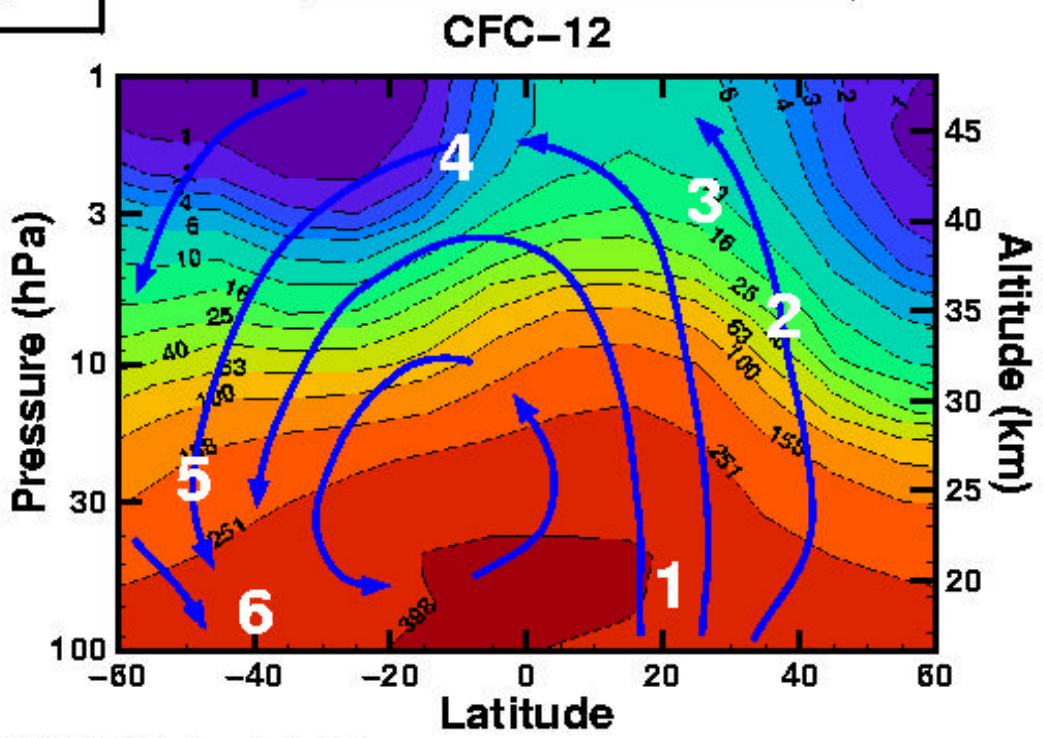
Chlorine life cycle

4) $Cl + CH_4 \rightarrow HCl + CH_3$
$ClO + NO_2 \rightarrow ClONO_2$
HCl and $ClONO_2$ are photolyzed, reintializing O_3 loss in step 3.

3) Cl catalytically destroys O_3
$Cl + O_3 \rightarrow ClO + O_2$
$ClO + O \rightarrow Cl + O_2$
Net: $O_3 + O \rightarrow 2\ O_2$
~ 1000 O_x lost

5) HCl and $ClONO_2$ react on the surfaces of PSCs to form Cl_2. Cl_2 photolyzed by weak sunlight. Molina–Molina catalytic reactions (mainly) produce massive spring ozone losses

6) HCl and $ClONO_2$ are eventually transported into the troposphere where they are rained out. Approximately 100,000 O_3 molecules are destroyed by Cl in steps 3, 4, and 5.

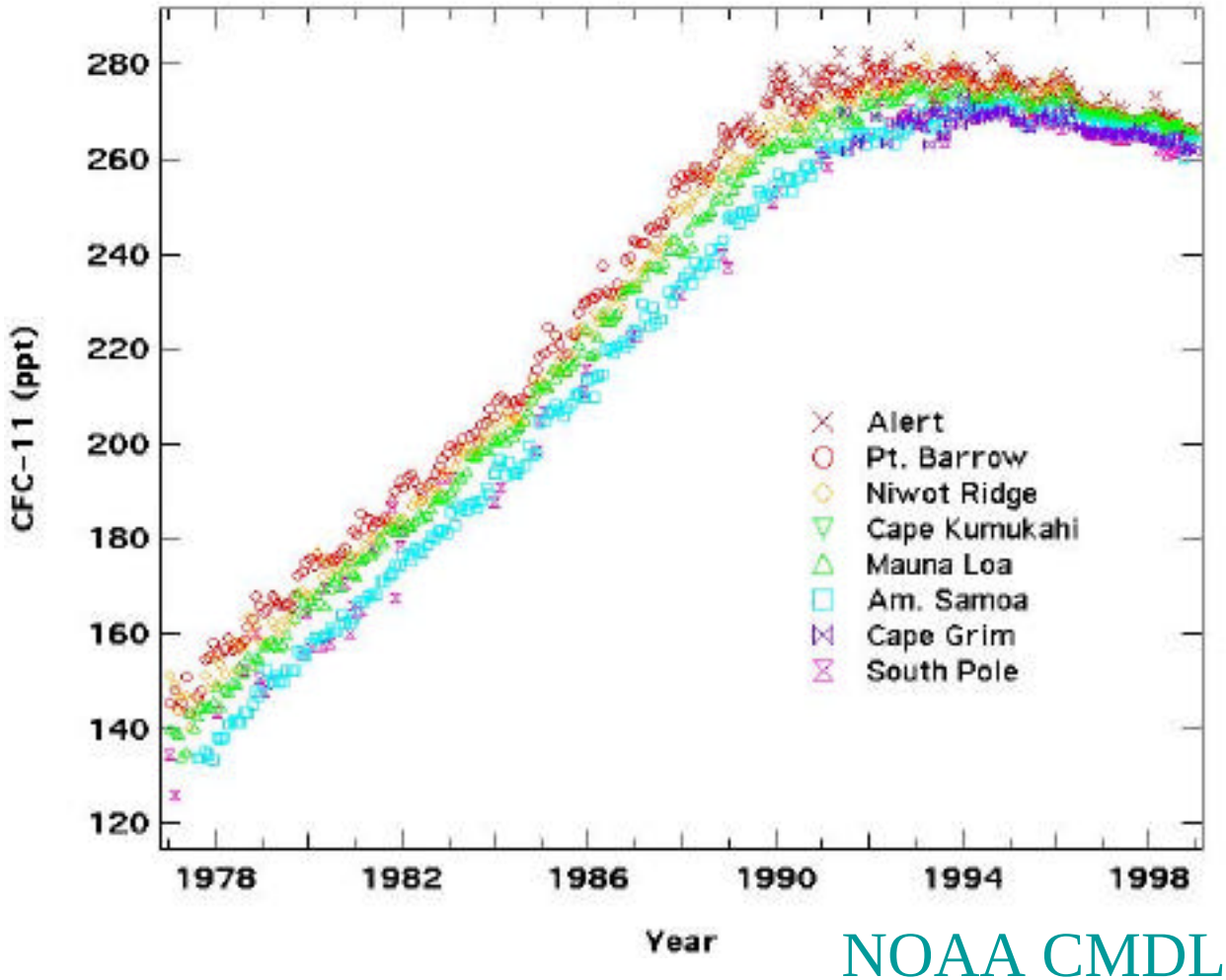


UARS–CLAES, June–July 1992

2) F12 is photolyzed by solar UV ($\lambda < 240$ nm) as it rises above the ozone peak, releasing Cl (slow)

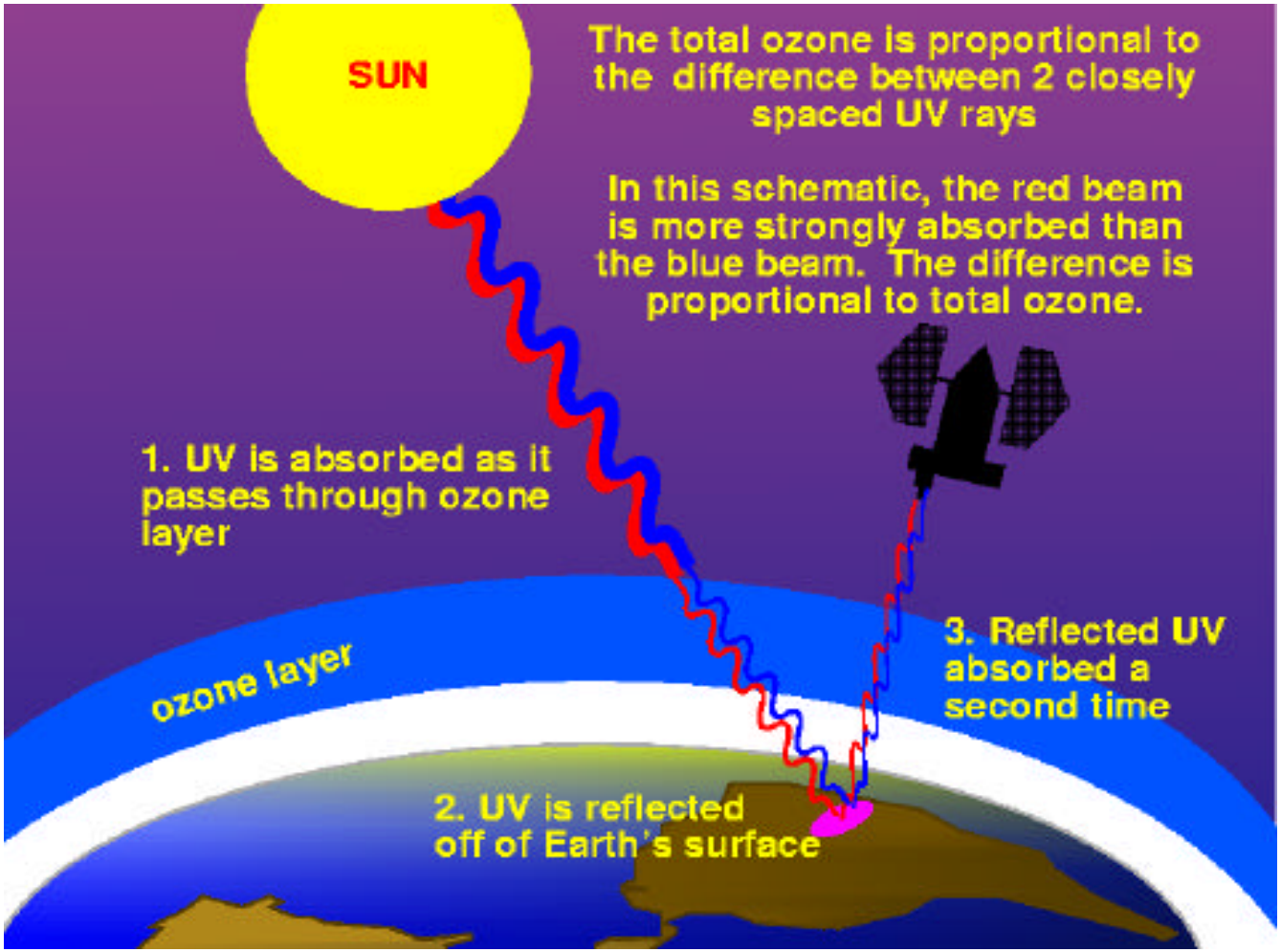
1) Tropospheric release of F12 (CCl_2F_2) is transported into the stratosphere in the tropics (slow!).

Cl Growth in the Atmosphere

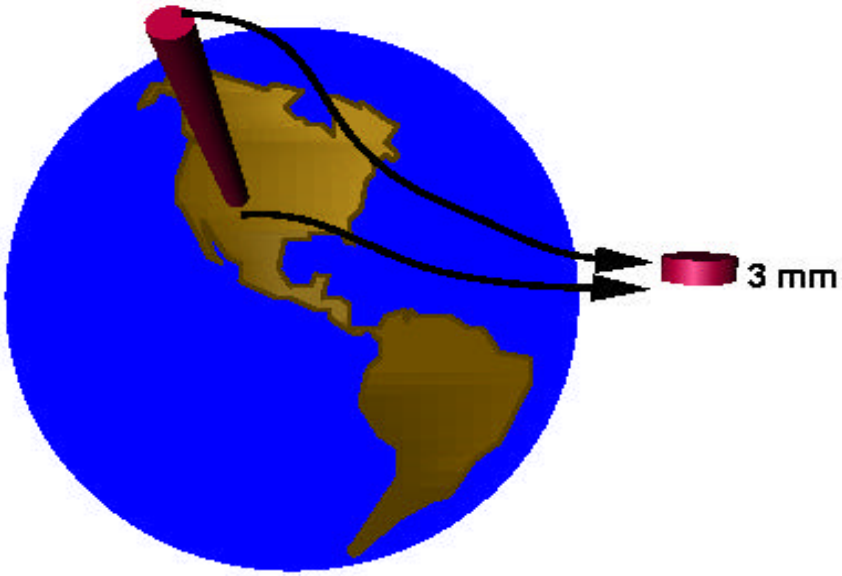


NOAA CMDL

Ozone Measurements by TOMS



Dobson Units



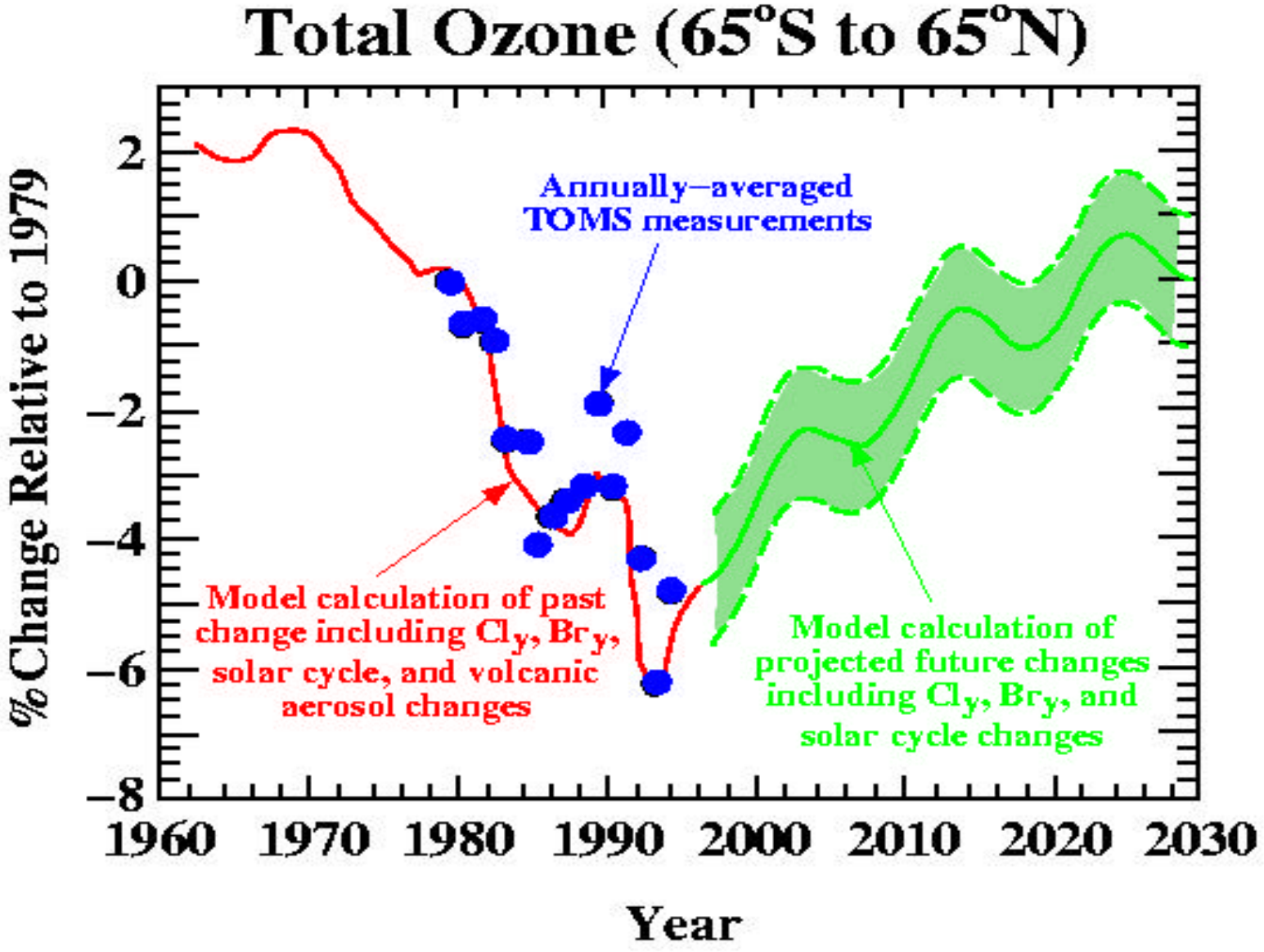
- Imagine that we could bring all ozone above a certain location down to the ground, at 0°C and 1 atmosphere pressure.
- The thickness of this layer is about 3 millimeters (~ 0.1 inch), the thickness of two stacked pennies. This corresponds to 300 Dobson Units (approximately the global average).
- 100 Dobson Units is 1 millimeter thick (approximately the thickness of ozone in the Antarctic ozone hole), the thickness of one dime.

☛ The Dobson Unit is a convenient unit of measurement for total column ozone.

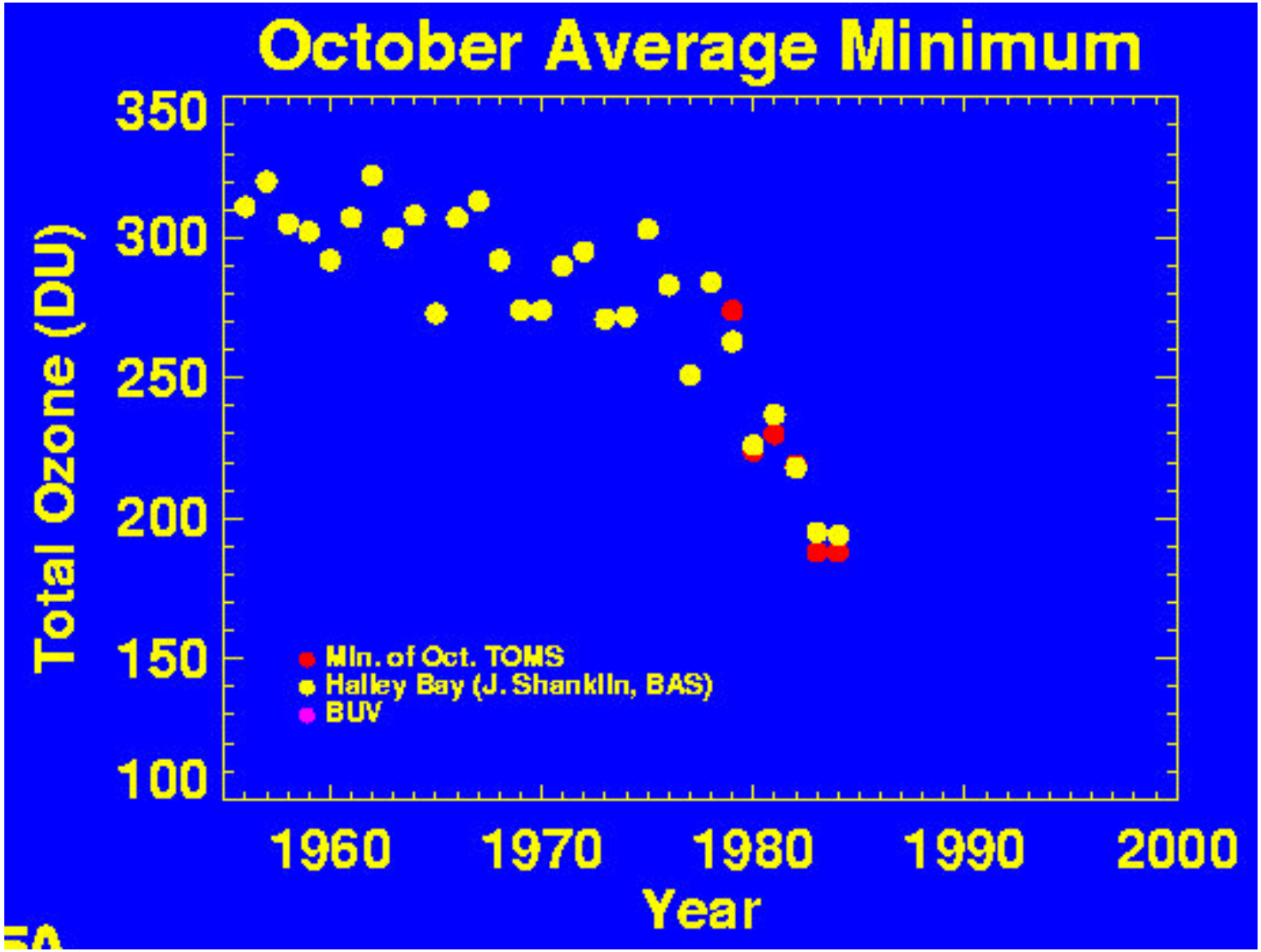
Ozone trends

- Global trends
- Antarctic ozone hole
- Arctic ozone losses

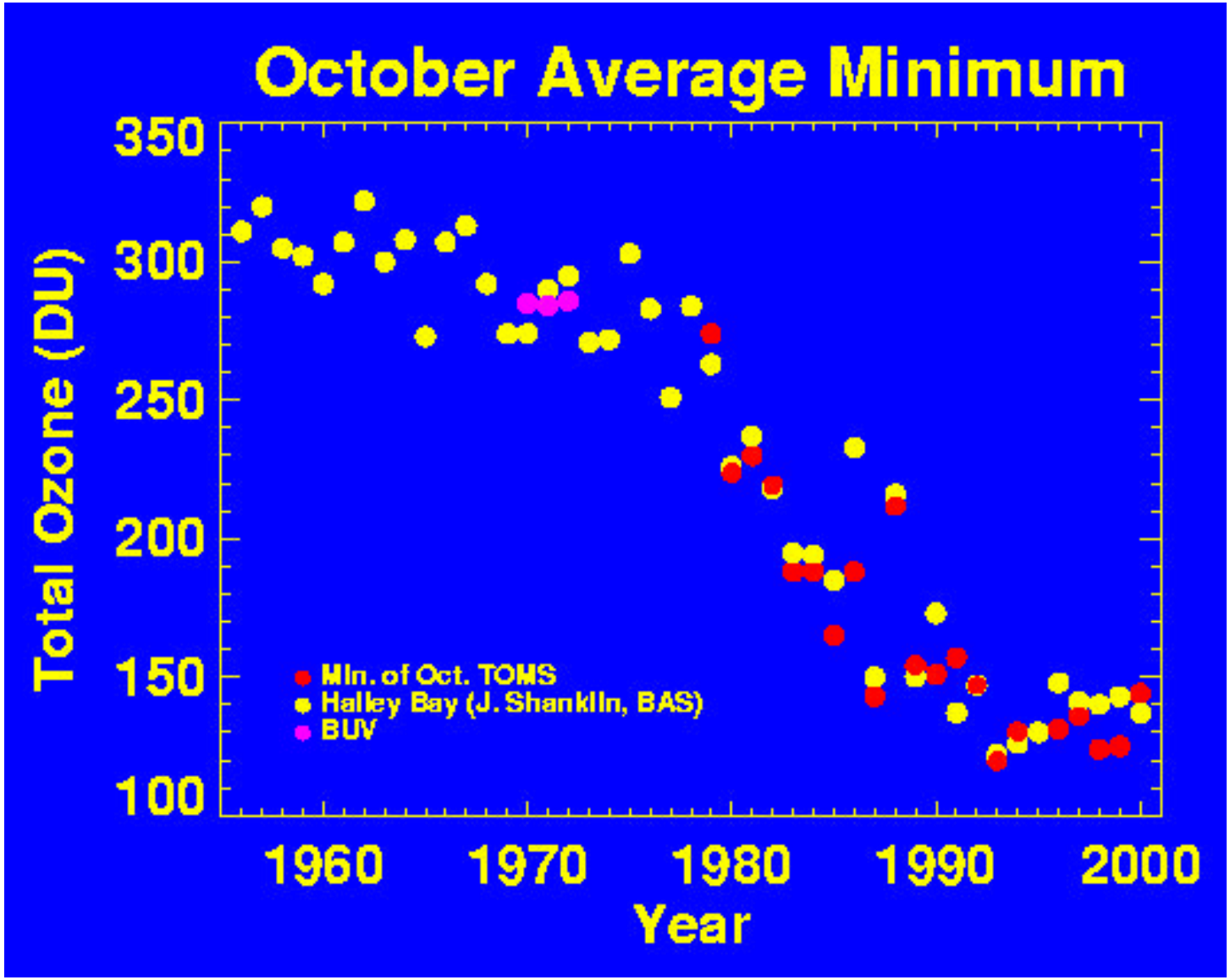
Global Trends



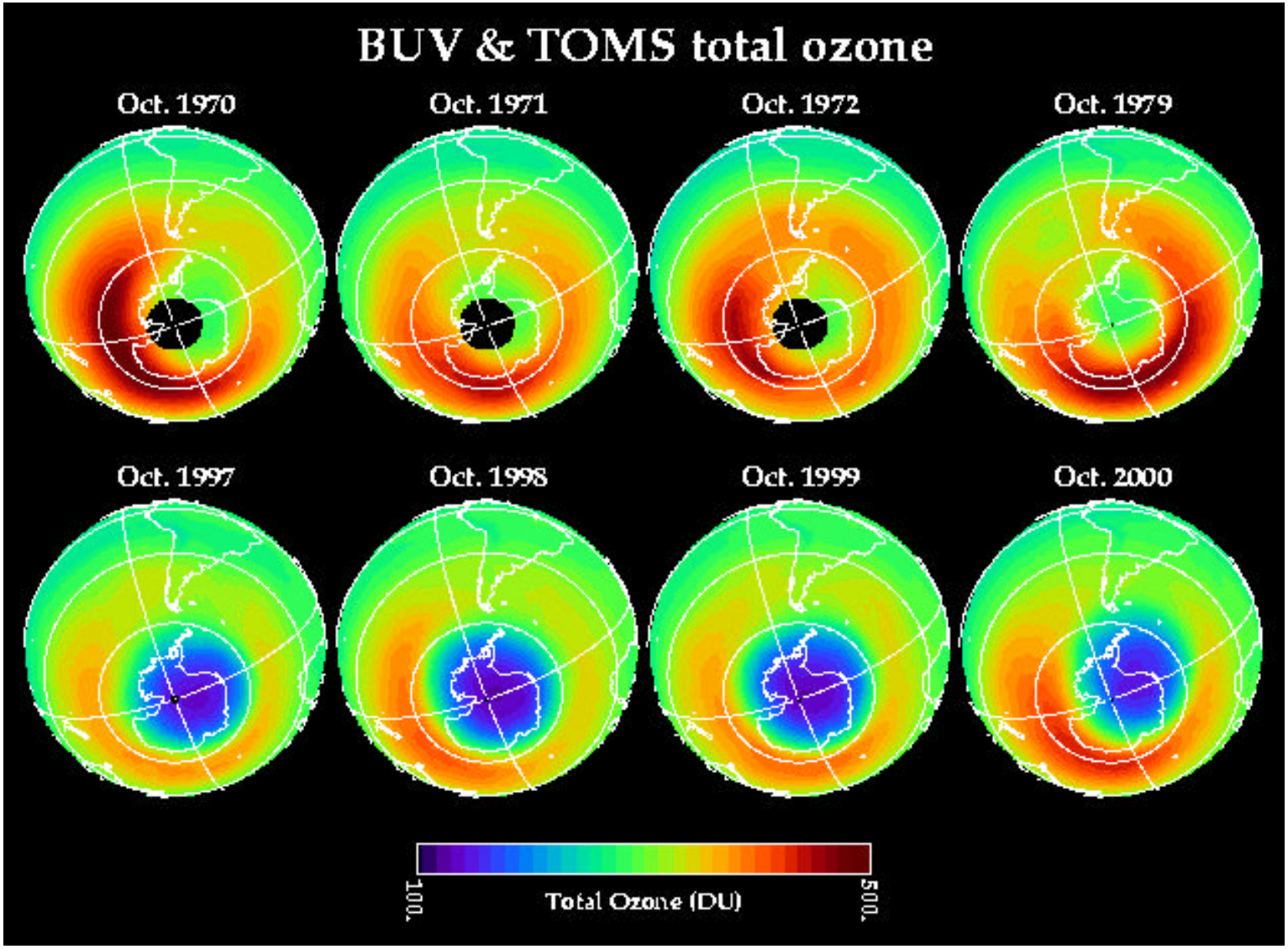
Antarctic Ozone Hole - vintage 1984



Antarctic Ozone Hole



Antarctic Ozone Hole Images



1998 Ozone Hole Movie

Antarctic ozone hole sequence of events

April-May:

- Polar vortex forms & temperatures cool

May-June:

- First appearance of polar stratospheric clouds as temperatures fall to -78˚C: ternary solutions, nitric acid hydrates, ice particles.

June-July:

- Continued cooling & formation of PSCs
- Surface reactions on PSCs ($HCl + ClONO_2 \rightarrow Cl_2 + HNO_3$)
- Dehydration and denitrification

August-September:

- Sun begins to rise over North Polar region
- Cl_2 + light $\rightarrow$ 2 ClO
- Catalytic ozone destruction by ClO

October:

- Culmination of ozone losses
- Conversion of ClO to $ClONO_2$ and HCl as temps rise above -78˚C : ozone destruction stops

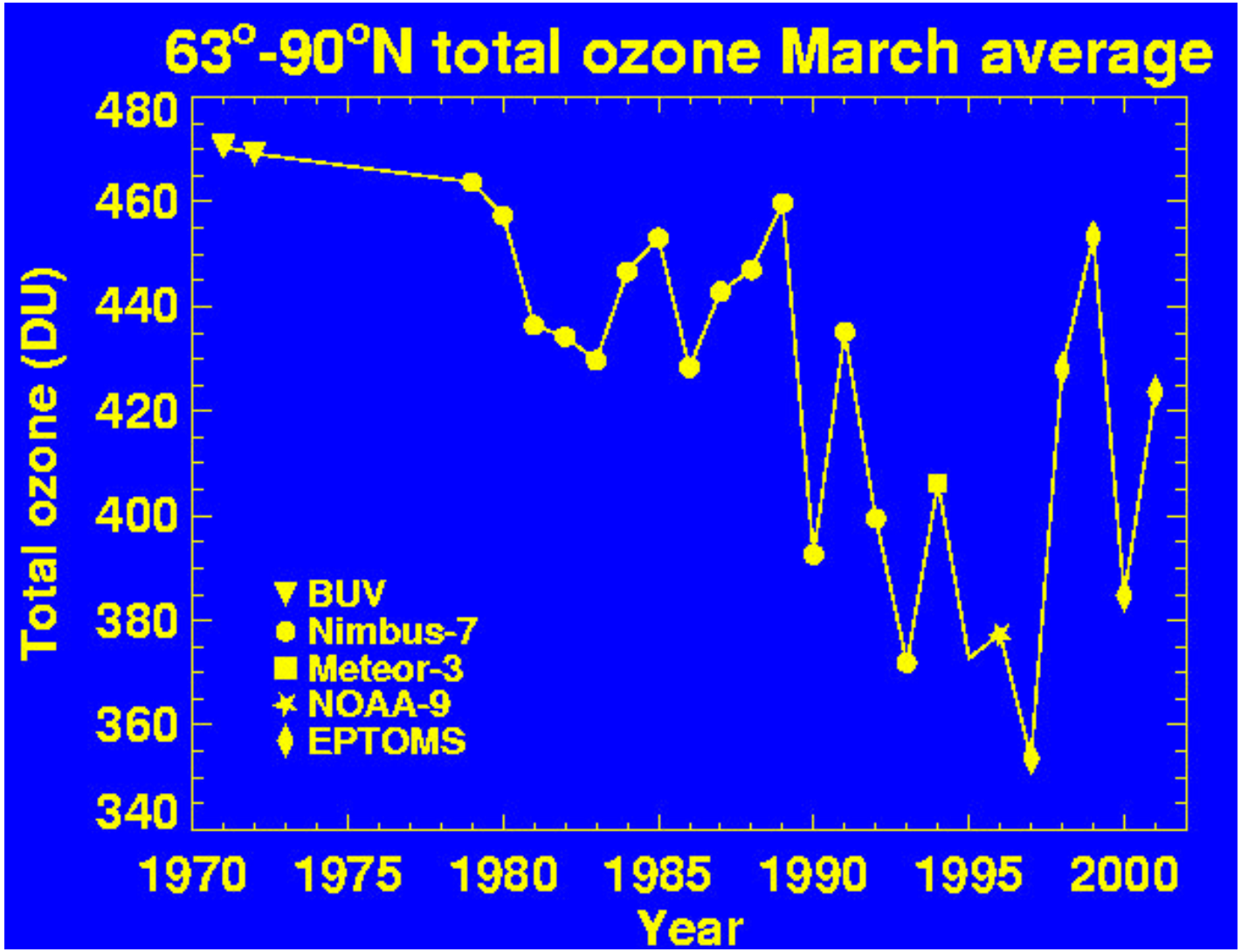
November:

- Vortex breakdown in late November, ozone hole mixes across Southern Hemisphere

Polar Stratospheric Cloud

Kiruna, Sweden January 27, 2000

March Arctic Ozone Trends



Summary

- Ozone is a critical gas for screening ultraviolet solar radiation
- Ozone is being destroyed by human-produced chlorine and bromine compounds that have accumulated in our atmosphere
- Large losses of ozone have been observed in the Antarctic and Arctic
- Smaller losses have been observed in the mid-latitudes
- CFCs and Halons have stopped growing in the atmosphere because of International agreements to halt production
- Ozone should show recovery within the next decade
    - Worries about compliance
    - Climate change impact on the stratosphere

What can you do?

- Avoid excessive solar exposure (avoid the sun between 11AM and 2PM).
- Wear and encourage others to wear sunscreen (SPF rating of 15). Even with sunscreen, prolonged exposure is not smart.
- Check your skin regularly.
- Wear sunglasses that screen UV.
- Hats and other coverings
- Make note of the UV index on the news or web:
  http://www.epa.gov/ozone/uvindex/uvover.html
  http://www.cpc.ncep.noaa.gov/products/stratosphere/uv_index/uv_current_map.html
- Read up on the topic!

Links

- On-line textbook
  http://see.gsfc.nasa.gov//edu/SEES/strat/class/S_class.htm
- EPA Home page on ozone
  http://www.epa.gov/docs/ozone/index.html
- Cambridge On-line ozone hole tour
  http://www.atm.ch.cam.ac.uk/tour/
- NOAA Climate Prediction Center stratospheric page
  http://www.cpc.ncep.noaa.gov/products/stratosphere/polar/polar.html
- Total Ozone Mapping Spectrometer
  http://toms.gsfc.nasa.gov/
- Robert Parson's Frequently Asked Questions on Ozone
  http://spot.colorado.edu/~rparson/ozone.html
- NOAA ozone web page
  http://www.ozonelayer.noaa.gov/